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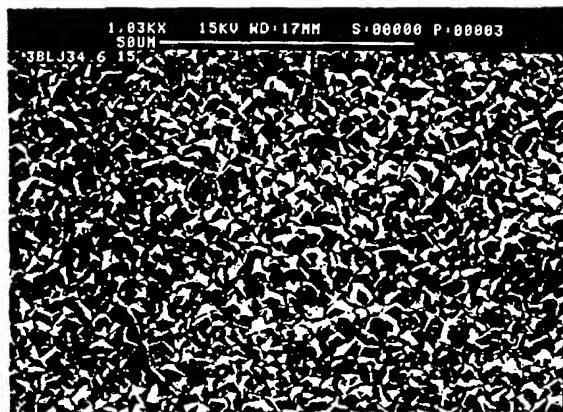
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(54) Title: OXIDE COATED CUTTING TOOL



(57) Abstract

According to the present invention there is provided a body coated with refractory single- or multilayers, wherein specific layers are characterized by a controlled microstructure and phase composition with crystal planes preferably grown in a preferential direction with respect to the surface of the coated body. Said coating comprises one or several refractory layers of which at least one layer is a dense, fine-grained layer of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> textured in the (104) direction. The Al<sub>2</sub>O<sub>3</sub>-coating is obtained by control of the oxidation potential of the CVD-reactor atmosphere prior to the nucleation of Al<sub>2</sub>O<sub>3</sub>, which is initiated by a controlled sequencing of the reactant gases. During the growth of the Al<sub>2</sub>O<sub>3</sub> a sulphur dopant is added, preferably H<sub>2</sub>S. The coated tool according to the invention exhibits excellent surface finish and shows much improved wear and toughness properties compared to prior art objects when used for machining steel, cast iron and, particularly, when machining nodular cast iron.

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OXIDE COATED CUTTING TOOL

The present invention relates to a coated cutting tool for chipforming machining.

5 Chemical Vapour Deposition (CVD) of alumina on cutting tools has been an industrial practice for more than 15 years. The wear properties of  $\text{Al}_2\text{O}_3$  as well as of other refractory materials have been discussed extensively in the literature.

10 The CVD-technique has also been used to produce coatings of other metal oxides, carbides and nitrides, the metal being selected from transition metals of the IVB, VB and VIB groups of the Periodic Table. Many of these compounds have found practical applications as  
15 wear resistant or protective coatings, but few have received as much attention as TiC, TiN and  $\text{Al}_2\text{O}_3$ .

Cemented carbide cutting tools coated with various types  $\text{Al}_2\text{O}_3$ -coatings, e.g., pure  $\kappa$ - $\text{Al}_2\text{O}_3$ , mixtures of  $\kappa$ -and  $\alpha$ - $\text{Al}_2\text{O}_3$  and very coarse-grained  $\alpha$ - $\text{Al}_2\text{O}_3$  have been  
20 commercially available for many years.  $\text{Al}_2\text{O}_3$  crystalizes in several different phases:  $\alpha$ ,  $\kappa$ ,  $\gamma$ ,  $\beta$ ,  $\theta$  etc.

The two most frequently occurring phases in CVD of wear resistant  $\text{Al}_2\text{O}_3$ -coatings are the thermodynamically stable, hexagonal  $\alpha$ -phase and the metastable  $\kappa$ -phase.  
25 Generally, the  $\kappa$ -phase is fine-grained with a grain size in the range 0.5-2.0  $\mu\text{m}$  and often exhibits a columnar coating morphology. Furthermore,  $\kappa$ - $\text{Al}_2\text{O}_3$  coatings are free from crystallographic defects and free from micropores or voids.

30 The  $\alpha$ - $\text{Al}_2\text{O}_3$  grains are usually coarser with a grain size of 1-6  $\mu\text{m}$  depending upon the deposition conditions. Porosity and crystallographic defects are in this case more common.

Often both  $\alpha$ - and  $\kappa$ -phase are present in a CVD alumina coating deposited onto a cutting tool. In commer-

cial cutting tools,  $\text{Al}_2\text{O}_3$  is always applied on TiC coated carbide or ceramic substrates (see, e.g. U.S. Pat. No. 3,837,896, now Reissue U.S. Pat. No. 29,420) and therefore the interfacial chemical reactions 5 between the TiC-surface and the alumina coating are of particular importance. In this context the TiC layer should also be understood to include layers having the formula  $\text{TiC}_x\text{N}_y\text{O}_z$  in which the carbon in TiC is completely or partly substituted by oxygen and/or 10 nitrogen.

The practice of coating cemented carbide cutting tools with oxides to further increase their wear resistance is in itself well known as is evidenced in e.g. U.S. Pat. Reissue No. 29,420 and U.S. Pat. Nos. 15 4,399,168, 4,018,631, 4,490,191 and 4,463,033. These patents disclose oxide coated bodies and how different pretreatments e.g. of TiC-coated cemented carbide, enhance the adherence of the subsequently deposited oxide layer. Alumina coated bodies are further disclosed in 20 U.S. Pat. No. 3,736,107, 5,071,696 and 5,137,774 wherein the  $\text{Al}_2\text{O}_3$  layers comprise  $\alpha$ ,  $\kappa$  resp  $\alpha+\kappa$  combinations.

US 4,619,866 describes a method for producing fast growing  $\text{Al}_2\text{O}_3$  layers by utilizing a hydrolysis reaction 25 of a metal halide under the influence of a dopant e.g. hydrogen sulphide ( $\text{H}_2\text{S}$ ) in the concentration range 0.01-0.2 % at a CVD deposition temperature 1000-1050°C. Under these process conditions, essentially two phases of  $\text{Al}_2\text{O}_3$ , the  $\alpha$ - and the  $\kappa$  phases, are produced. The 30 resulting coating consists of a mixture of the smaller  $\kappa$ -grains and the larger  $\alpha$ -grains. The process yields coatings with an even layer thickness distribution around the coated body.

Swedish patent application 9101953-9 discloses a 35 method of growing a finegrained  $\kappa$ -alumina coating.

In Swedish Patent Application No. 9203852-0 a method is disclosed for obtaining a fine grained, (012)-textured  $\alpha$ - $\text{Al}_2\text{O}_3$ -coating. This particular  $\text{Al}_2\text{O}_3$ -coating applied on cemented carbide tools has been 5 found particularly useful for machining of cast-iron.

Swedish Patent Application No. 9304283-6 discloses a body with a coating comprising one or more refractory layers of which at least one layer is a layer of  $\alpha$ - $\text{Al}_2\text{O}_3$  textured in the (110) direction. The alumina 10 layer is essentially free of cooling cracks and comprises platelike grains with a length of 2-8  $\mu\text{m}$  and a length/width-ratio of 1 - 10.

The object of the present invention is, thus, to provide onto a hard substrate or preferably onto aforementioned  $\text{TiC}_x\text{N}_y\text{O}_z$  coating at least one single phase  $\text{Al}_2\text{O}_3$  layer of the polymorph  $\alpha$  with a desired micro-structure and crystallographic texture using suitable nucleation and growth conditions such that said properties of the  $\text{Al}_2\text{O}_3$  layer are stabilized.

20 It is a further object of the invention to provide an alumina coated cutting tool insert with improved cutting performance in steel, stainless steel, cast iron and in nodular cast iron.

Fig 1 shows a Scanning Electron Microscope (SEM) 25 top-view micrograph at 1000X magnification of a typical  $\text{Al}_2\text{O}_3$ -coating according to the invention.

According to the invention there is provided a cutting tool comprising a body of a hard alloy onto which a wear resistant coating has been deposited. The coating 30 comprises one or several refractory layers of which at least one layer is a dense, fine-grained and preferably textured  $\text{Al}_2\text{O}_3$ -layer of the polymorph  $\alpha$ .

A coated cutting tool according to the present invention exhibits improved wear and toughness properties 35 compared to prior art tools when used for machining.

steel or cast iron particularly if the surface has been further smoothened by wet blasting.

More specifically, the coated tool comprises a substrate of a sintered cemented carbide body, cermet or a 5 ceramic body preferably of at least one metal carbide in a metal binder phase. The individual layers in the coating structure may be TiC or related carbide, nitride, carbonitride, oxycarbide and oxycarbonitride of a metal selected from the group consisting of metals 10 in the Groups IVB, VB, and VIB of the Periodic Table, B, Al and Si and/or mixtures thereof. At least one of said layers is in contact with the substrate. However, at least one of the layers in the coating structure comprises a fine-grained, dense, single phase  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> 15 coating free of microporosity and crystallographic defects. This coating is preferentially textured with a thickness of  $d = 0.5\text{--}25 \mu\text{m}$  with an average grain size (s) of

$0.5 \mu\text{m} < s < 1 \mu\text{m}$  for  $0.5 \mu\text{m} < d < 2.5 \mu\text{m}$  and  
20  $0.5 \mu\text{m} < s < 4 \mu\text{m}$  for  $2.5 \mu\text{m} < d < 25 \mu\text{m}$

The fine-grained microstructure comprises a narrow grain size distribution. Most often 80 % of the Al<sub>2</sub>O<sub>3</sub> grains have a grain size of  $\pm 50$  % of the average grain-size.

25 The grain-size of the Al<sub>2</sub>O<sub>3</sub>-coating is determined from a SEM top view micrograph at 5,000X magnification. Drawing three straight lines in random directions, the average distances between grain boundaries along the lines, are taken as a measure of the grain-size.

30 The Al<sub>2</sub>O<sub>3</sub>-layer according to the invention has a preferred crystal growth orientation in the (104) direction which is determined by X-ray Diffraction (XRD) measurements. A Texture Coefficient, TC, can be defined as:

$$TC(hkl) = \frac{I(hkl)}{I_0(hkl)} \left\{ \frac{1}{n} \sum \frac{I(hkl)}{I_0(hkl)} \right\}^{-1}$$

where

I(hkl) = measured intensity of the (hkl) reflection

5 I<sub>0</sub>(hkl) = standard intensity of the ASTM standard powder pattern diffraction data

n = number of reflections used in the calculation,  
(hkl) reflections used are: (012), (104), (110), (113),  
(024), (116)

10 According to the invention TC for the set of (104) crystal planes is larger than 1.5, preferably larger than 2.5, and most preferably larger than 3.0.

The coated body according to the invention is further characterized by a surface roughness (R<sub>a</sub>) of  
15 the refractory coating of less than 0.3 μm over a measured length of 0.25 mm. Preferably, the Al<sub>2</sub>O<sub>3</sub>-layer is an exposed outermost layer.

The textured Al<sub>2</sub>O<sub>3</sub>-coating according to the invention is obtained by careful control of the oxidation potential of the CVD-reactor atmosphere prior to the nucleation of Al<sub>2</sub>O<sub>3</sub>. The total concentration level of H<sub>2</sub>O or other oxidizing species should preferably be below 5 ppm. However, the nucleation of Al<sub>2</sub>O<sub>3</sub> is initiated by a controlled sequencing of the reactant gases  
25 as follows: CO<sub>2</sub> and CO are first entering the reactor in a H<sub>2</sub> free atmosphere e.g. in the presence of N<sub>2</sub> or/and Ar then H<sub>2</sub> and AlCl<sub>3</sub> are allowed into the reactor. The temperature shall be 850-1100 °C, preferably 950-1000°C, during the nucleation. However, the exact  
30 conditions depend to a certain extent on the design of the equipment used. It is within the purview of the skilled artisan to determine whether the requisite texture and coating morphology have been obtained and to modify the nucleation and the deposition conditions in

accordance with the present specification, if desired, to effect the amount of texture and coating morphology.

Example 1

5       A) Cemented carbide cutting inserts with the composition 6.5 % Co, 8.5 % cubic carbides and balance WC were coated with a 5.5  $\mu\text{m}$  thick layer of TiCN. In subsequent process steps during the same coating cycle, a 6  $\mu\text{m}$  thick layer of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> was deposited. Prior to the  
10 nucleation, the oxidation potential of the hydrogen carrier gas, i.e. the water vapour concentration, was explicitly set forth to a low level, less than 5 ppm (See also U.S. Pat. No. 5,071,696).

A hydrogen free reaction gas mixture comprising N<sub>2</sub>,  
15 CO<sub>2</sub> and CO was first introduced into the CVD-reactor. The reaction gases were sequentially added in the given order. After a preset time H<sub>2</sub> and AlCl<sub>3</sub> were allowed into the reactor. During the deposition of Al<sub>2</sub>O<sub>3</sub>, H<sub>2</sub>S was used as a dopant.

20      The gas mixtures and other process conditions during the Al<sub>2</sub>O<sub>3</sub> deposition steps comprised:

Step	1.	2
CO <sub>2</sub>	4%	4%
AlCl <sub>3</sub>	4%	4%
25     CO	2%	-
H <sub>2</sub> S	-	0.2%
HCl	1%	4%
H <sub>2</sub>	balance	balance
Pressure	55 mbar	100 mbar
30     Temperature	1000°C	1000°C
Duration	1 hr	7.5 hr

XRD-analysis showed a texture coefficient, TC(104), of 3.2 of the (104) planes in the single  $\alpha$  phase of the  
35 Al<sub>2</sub>O<sub>3</sub> coating.

SEM-studies showed a fine grained, 6  $\mu\text{m}$  thick  $\text{Al}_2\text{O}_3$ -coating with an average grain size of = 2.1  $\mu\text{m}$ .

B) The cemented carbide substrate of A) was coated with TiCN (5.5  $\mu\text{m}$ ) and  $\text{Al}_2\text{O}_3$  (6  $\mu\text{m}$ ) as set forth in A)  
5 except that the  $\text{Al}_2\text{O}_3$  process was carried out according to prior art technique resulting in a mixture of coarse  $\alpha$ - and fine  $\kappa$ - $\text{Al}_2\text{O}_3$  grains in the coating.

Coated tool inserts from A), and B) were all wet blasted with 150 mesh  $\text{Al}_2\text{O}_3$  powder in order to smoothen  
10 the coating surface.

The cutting inserts were then tested with respect to edge line and rake face flaking in a facing operation in nodular cast iron (AISI 60-40-18, DIN GGG40).  
15 The shape of the machined work piece was such that the cutting edge is intermittent twice during each revolution.

Cutting data:

Speed = 150 m/min,  
Cutting Depth = 2.0 mm and  
20 Feed = 0.1 mm/rev.

The inserts were run one cut over the face of the work piece.

The results are expressed in the table below as percentage of the edge line in cut that obtained flaking as well as the rake face area subjected to flaking in relation to total contact area between the rake face and the work piece chip.  
25

	Flaking (%)	
	Edge line	Rake face
A) single phase/textured $\alpha$ - $\text{Al}_2\text{O}_3$	5	6 (acc. to the invention)
B) $\alpha+\kappa$ $\text{Al}_2\text{O}_3$	90	86

Example 2

The cutting inserts from A) and B) were also tested with respect to edge line flaking in a facing operation  
5 in an alloyed steel (AISI 1518, W-no. 1,0580). The shape of the machined work piece was such that the cutting edge is intermittent three times during each revolution.

Cutting data:

10 Speed = 130-220 m/min,  
Cutting Depth = 2 mm and  
Feed = 0.2 mm/rev.

The inserts were run one cut over the face of the work piece.

15 The result below is expressed as percentage of the edgeline in cut that obtained flaking.

		Flaking (%)	
		Edge line	
20	D) single phase/textured $\alpha\text{-Al}_2\text{O}_3$	0	(according to the invention)
	E) $\alpha+\kappa\text{ Al}_2\text{O}_3$	28	

## CLAIMS

1. Body at least partially coated with one or more refractory layers of which at least one layer is alumina characterized in said alumina layer having a thickness of  $d = 0.5\text{--}25 \mu\text{m}$  with grain size ( $s$ ):

$0.5 \mu\text{m} < s < 1 \mu\text{m}$  for  $0.5 \mu\text{m} < d < 2.5 \mu\text{m}$  and  
 $0.5 \mu\text{m} < s < 4 \mu\text{m}$  for  $2.5 \mu\text{m} < d < 25 \mu\text{m}$ .

and consisting of single phase  $\alpha$ -structure textured in the (104)-direction with a texture coefficient larger than 1.5 preferably larger than 2.5. and most preferably larger than 3.0 the texture coefficient being defined as below:

15

$$TC(hkl) = \frac{I(hkl)}{I_0(hkl)} \left\{ \frac{1}{n} \sum \frac{I(hkl)}{I_0(hkl)} \right\}^{-1}$$

where

$I(hkl)$  = measured intensity of the  $(hkl)$  reflection

20  $I_0(hkl)$  = standard intensity of the ASTM standard powder pattern diffraction data

$n$  = number of reflections used in the calculation

$(hkl)$  reflections used are: (012), (104), (110), (113), (024), (116).

25 2. Body according to any of the preceding claims characterized in that said alumina layer is an exposed outermost layer.

30 3. Body according to any of the preceding claims characterized in that said alumina layer is in contact with a  $TiC_xN_yO_z$ -layer.

4. Body according to claim 5

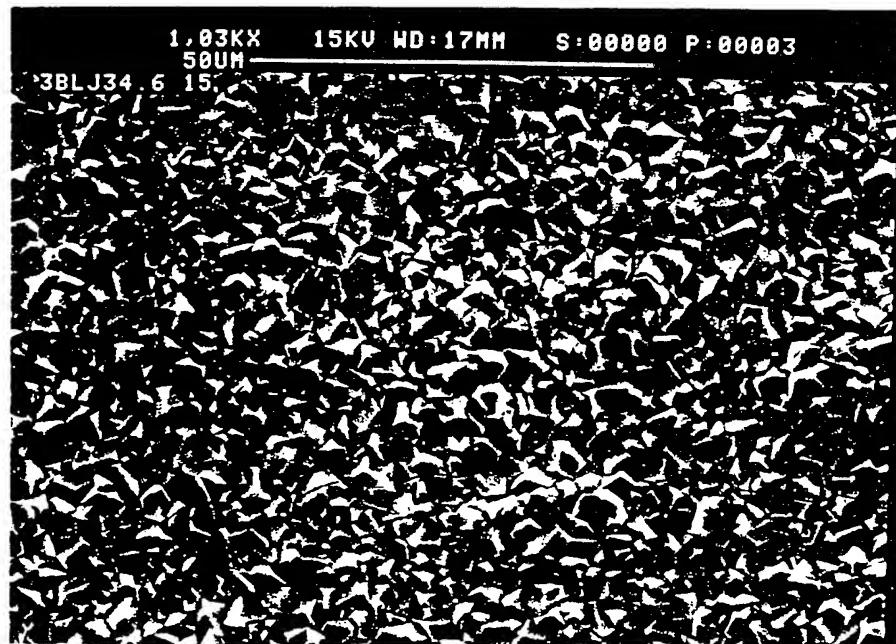
characterized in that said  $TiC_xN_yO_z$ -layer is the innermost layer of the coating.

35 5. Body according to any of the preceding claims characterized in that said body is a cut-

ting tool insert of cemented carbide, titanium based carbonitride or ceramics.

6. Method of coating a body with an  $\alpha$ -alumina coating at which the body is brought in contact with a  
5 hydrogen carrier gas containing one or more halides of aluminium and a hydrolyzing and/or oxidizing agent at high temperature c h a r a c t e r i z e d in that the oxidation potential of the CVD-reactor atmosphere prior to the nucleation of  $\text{Al}_2\text{O}_3$  is kept at a low level using  
10 a total concentration of  $\text{H}_2\text{O}$  or other oxidizing species preferably below 5 ppm, that the nucleation of  $\text{Al}_2\text{O}_3$  is started up by controlled sequencing of the reactant gases that  $\text{CO}_2$  and CO are entering the reactor first in an  $\text{N}_2$  and/or Ar atmosphere followed by  $\text{H}_2$  and  $\text{AlCl}_3$ ,  
15 that the temperature is preferably between 950-1000°C during the nucleation and that during the growth of the  $\text{Al}_2\text{O}_3$  a sulphur dopant is added, preferably  $\text{H}_2\text{S}$ .

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**Fig. 1**